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Advances on the Development of the Parabolic Trough Technology in Mexico

Carlos Ramos*, Jose Beltran, Rafael Ramirez

Instituto de Investigaciones Electricas (IIE), Reforma 113 Col. Palmira, Cuernavaca Morelos C.P. 62490, Mexico

Abstract

The current tendencies of the concentrating solar technologies present an excellent potential to contribute in next decades with a significant way to the electric power production and process heat for industrial uses. Concentrating solar technologies are appropriate for a wide range of applications in the process heat generation and of great utility for the industry that requires thermal energy for their processes. Among solar thermal concentrating technologies, parabolic trough technology is one of the most promising in such sense. In an industrial installation the solar system could give heat for the preheating of water and even steam generation. For testing purposes and for demonstration of the parabolic trough technology several prototypes have been developed by the Electric Research Institute (IIE). Each prototype includes a parabolic trough concentrator, mounted on a one-axis tracking structure. Anodized aluminum sheet with a solar reflectivity of 90% was used as reflective material. These prototypes were installed in different places and provided a lot information concerning to the operation and maintenance activities, elaboration of methodological guides for the development of similar applications and the identification and establishment of mechanisms of collaboration with national industry to involve them in the technological development of parabolic trough components. Recently the IIE erected a small experimental facility in a local University near Cuernavaca, Mexico. In this paper, we present the design features as well as the construction development of the prototypes. Also, the operational experience and the maintenance strategies on the reflective surface, the tracking system and lessons learned over the time are described.

Keywords: Parabolic Trough, Solar Tracker, concentrating solar

* Tel.: +52 777 3183811; fax: +52 777 3182436.
E-mail address: cramos@iie.org.mx.

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1. Introduction

Solar energy is an abundant resource in Mexico, but also abundant oil that not only serves as fuel to power the economy, but also as a source of income for investment in social and economic development [1]. However, the current energy policy of the country emphasizes the need for a more diversified energy portfolio, as a means to enhance future energy security and to avoid further environmental degradation. In recent years, private and government organizations in Mexico have been actively promoting the use of renewable in various sectors of the national economy. There are technologies for the exploitation of that resource with practical purposes, several of them being economically competitive for certain market niches. In recent years, the world market of these technologies has grown in such way that has allowed the appearance of new industries and the creation of new employment sources. This fact, jointly with the benefits for the environment derived by the use of this energy source, has motivated governments in several countries to establish development programs for the use of the solar energy [2]. At the present time Concentrating Solar Technologies (CST) are the most efficient and cost-effective way to generate electricity from the sun with a high potential of excellent application. CST technologies are usually classified in three different concepts: towers, dishes and troughs. Tower system uses numerous two axis tracking mirrors called heliostats to concentrate sunlight onto a central receiver on the top of a tower. Dish system use parabolic dish concentrator to concentrate the light of the sun on a focal zone, reaching the highest concentration ratios, where a Stirling engine can be placed to generate electricity. Trough system use parabolic trough-shaped mirror reflectors linearly concentrate sunlight onto receiver tubes, heating a thermal transfer fluid which is then used to produce superheated steam and then used to generate electricity in a conventional turbine steam. Even though, the current tendencies of the CST present an excellent potential to the electric power production could be very interesting option to the process heat for industrial uses. Among solar thermal concentrating technologies, parabolic trough technology is one of the most promising in such sense. Parabolic troughs are made by bending a sheet of reflective material into a parabolic shape. A metal tube covered with a glass tube to reduce heat losses is placed along the focal line of the parabola. The solar energy is absorbed in a working fluid (heat-transfer oil, water or steam), which is then piped to a central location to produce electricity or simply heat to be used in an industrial process. Because the parabolic trough will reflect only direct-beam sunlight, it uses single-axis tracking system to keep it facing the sun. The Parabolic trough is the most mature technology to generate heat at temperatures up to 400 °C for solar thermal electricity or process heat applications. For testing purposes and for demonstration of the parabolic trough technology several prototypes have been developed by the Instituto de Investigaciones Electricas. Each prototype includes a parabolic trough concentrator, mounted on a one-axis tracking structure. Anodized aluminum sheet with a solar reflectivity of 90% was used as reflective material. These prototypes can be classified according to three generations; see Fig.1, each generation was focused on specific ideas to get a specific product for the Mexican industry: assimilation of the concept (1st generation), optimization of manufacture and costs (2nd generation) and maximize capacity (last generation).

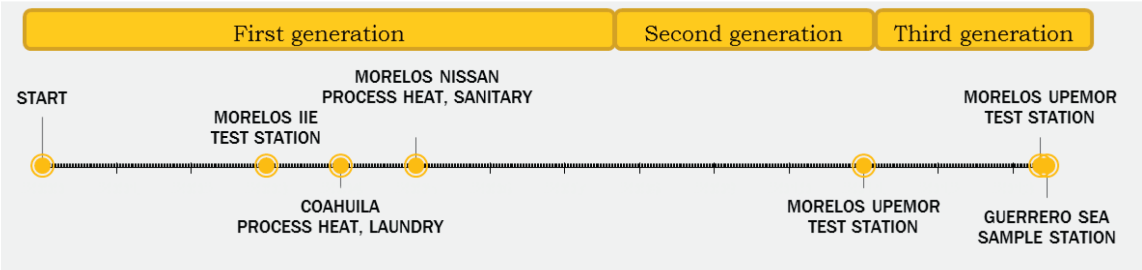


Fig. 1. Parabolic trough development

2. Development of prototypes

Development of the parabolic trough technology was carried out by design and construction several prototypes, improving each one with the lessons learned with the last prototype. The improvements made to the prototypes can be divided into three generations within which identifies a specific purpose in the development line.

2.1. First generation, assimilation of the concept

The first generation of parabolic trough prototype was focused on the concept assimilation and features that should meet each of its components; this prototype was implemented in three small facilities, see fig. 2, a test installation and two practical industrial applications, in different parts of the country. The first prototype was located at the IIE headquarters, the system was tested with a closed circuit using a storage tank and heat exchanger systems [3]. Second application was in an industrial laundry at northern Mexico, working to supplement the steam generation system for the ironing process. This installation allowed testing the system connected to an industrial process and the operation in other environmental conditions, with higher radiation levels to those observed in the first prototype and with higher wind speeds; the increase in the wind speed and the installation at the roof causes more forces to the structure.

Finally, a third prototype was installed in the NISSAN Company in Cuernavaca, Morelos. The heat generated by the parabolic trough system is used in showers for the workers of the plant [5]. The heat requirements of the company NISSAN increased with respect to the laundry at Torreon. Then, a new solution was tested, the modular design concept, with the installation of two equipment to get the demand of heat.

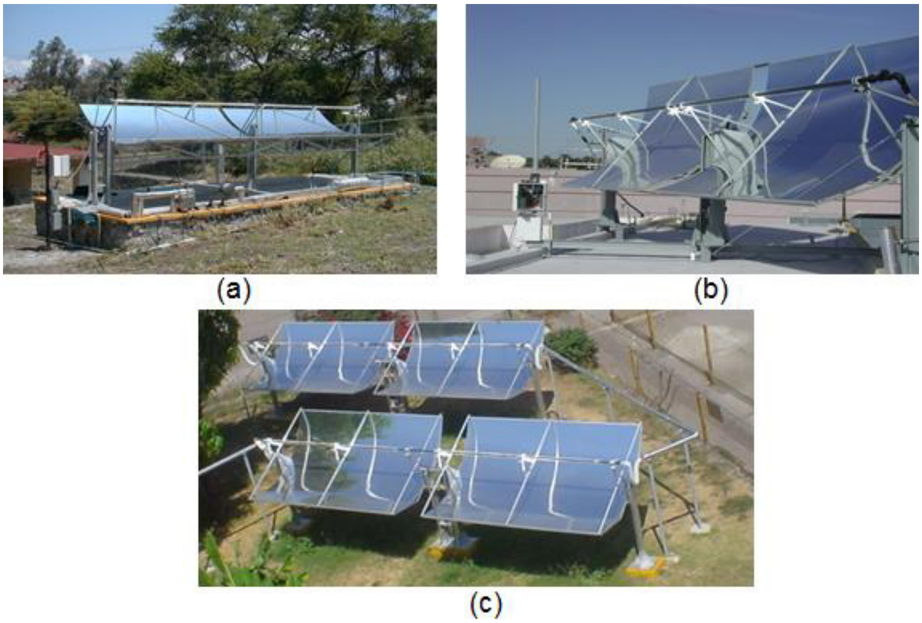
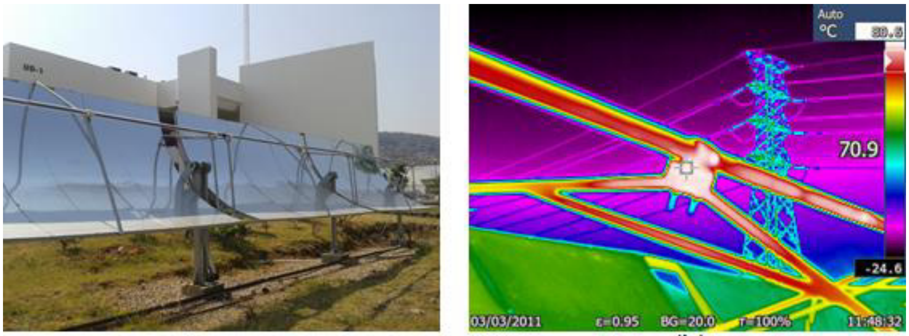


Fig. 2. First generation prototypes (a) Test station, Cuernavaca, Morelos; (b) Process Heat, Laundry, Torreón, Coahuila; (c) Process Heat, NISSAN, Cuernavaca, Morelos.

2.2. Second generation, optimization of production and costs

The first generation of prototype generated functional equipment as a result, allowed to identify opportunities for improvement, and at the second generation was looking to optimize system components to reduce cost and complexity in their manufacture. A specific system of solar tracking control was developed, which contributed significantly to reduce of the equipment cost and have greater control over functions of the system. The prototype increased to four sections driven by the same mechanism, which implied the use of a mechanical actuator with higher capacities, reducing the use of this element in large installations. This implementation is conditioned by the characteristics of the area where the equipment be installed. The elements from specific manufacturing were substituted with the use of commercial components with modifying the design of the structure [6]. According to above mentioned, a second generation prototype was build; and installed at the Polytechnic University of the Morelos State (UPEMOR), see fig. 3. This prototype allows functional testing to the thermal system and also allows the linking with academia and students and works as a showcase for the technology because is located at a visible site.



(a) (b)

Fig. 3. Second generation prototype (a) Test station UPEMOR, Jiutepec, Morelos; (b) Thermo camera test

2.3. Third generation, maximize capacities

Combining first and second generation of the development prototype functional equipment results and reduced costs showed that it is feasible to implement in industrial processes, with a large market and within the performance characteristics of the parabolic trough prototype.

In the new prototype the thermal capability was increased modifying two characteristics, the aperture and solar tracking system. To increase the temperature in the receiver, the aperture was increased achieving better thermal efficiency, to achieve this, the supporting structure was reinforced and reflective surface was increased. The solar tracking system was modified by using actuator arm larger and using the control implemented in the second generation, the largest dimensions actuator allowed greater movement and the control flexibility enable the implementation a new routine.

Two prototypes was manufactured for the last generation, one substituting the second generation prototype next to facilities in UPEMOR and a second prototype manufactured by the company Alternative Energy Systems (SEA in Spanish) that will be used for marketing, this prototype was installed in an industrial park, where the company has its headquarters in order to carry out their own tests and show it to potential investors, Fig. 4.

(a) (b)

Fig. 4. Third generation prototypes (a) Test station IIE Cuernavaca Morelos; (b) Sample station SEA, El Ocotito, Guerrero

3. Evolution of key components

The technology development was conducted conceptualizing each functionally parts, identifying the following components in the prototype: structure of the concentrator, the receiver and the solar tracking system. Each of them was developed and updated in every generation of prototypes with the functionalities to be served and the findings. The general characteristics of the prototypes and their evolution can be seen in Table 1, it evolution is described below

Table 1. Technical characteristics of the prototypes development

Parameter	First generation	Second generation	Third generation
Aperture width (m)	2.3	2.3	2.74
Length (m)	6.72	6.72	7.39
Rim angle (°)	72	72	72
Focal Length (m)	0.78	0.78	0.78
Reflective surface	Anodized aluminium	Anodized aluminium	Anodized aluminium
Receiver material	Steel	Steel	Steel
Receiver selective surface	Hight temperature black paint	Hight temperature black paint	Hight temperature black paint
Receiver outside diameter (m)	0.267	.267	.267
Receiver envelope	Glass tube	Glass tube	Glass tube
Collector tracking	E-W horizontal	E-W horizontal	E-W horizontal
Control system	Commercial	Own	Own
Actuator	Lineal 24”	Lineal 24”	Lineal 36”
Total weight (Incl. Pedestals) (kg) two sections	275	260	280

3.1. Concentrator structure

The structure consists of all the structural parabolic geometry achieved and allows the solar tracking system movement, including also the mirror surface. The reflective surface used since the first generation has been anodized aluminum for solar application, been tested with other materials for use as reflective surface [8], however for economy and design has not changed its use.

The design concept of the structure is space frame and has remained with slight modifications to the elements varying the supports of the receiver tube, the largest modification was made in the change from the second to the third generation to increase the dimensions thereof, and the resulting stresses are greater by weight and show larger surface exposed to wind. The structure was reinforced and validated by finite element analysis by obtaining a minimum deformation on the structure. See Fig. 5.

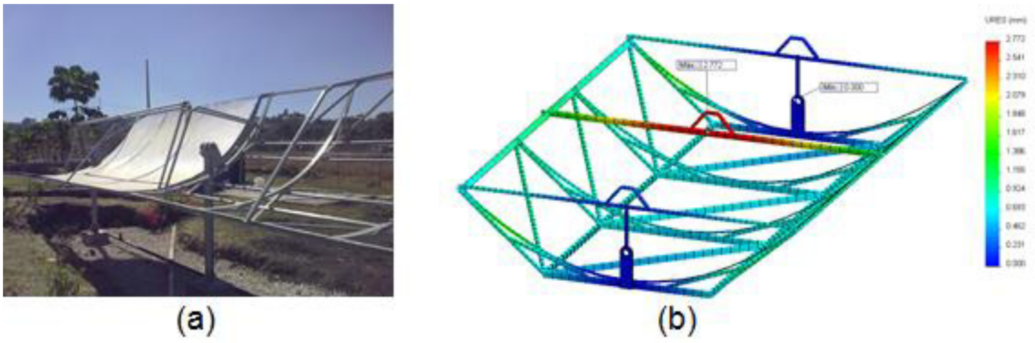


Fig. 5. Mechanical Structure (a) Second generation structure (b) Finite Element Analysis (FES) to the third generation structure

3.2. Receiver

The receiver is composed of coated steel pipe to obtain a selective surface and covered by a glass tube, the assembly is accomplished with the use of supports attached to a structure by a metal support. Its evolution has been to facilitate the assembly of the structure elements and switching to commercial components manufactured in specified way, see Fig. 6.

Fig. 6. Receiver (a) First generation receiver anchorage (b) Third generation receiver anchorage

3.3. Tracking system

The solar tracking system is composed by the linear actuator that performs the movement and the control system that performs the calculations necessary to carry out this activity. The evolution in the first element consisted using a larger component size and strong, moving a larger structure and weight and the same time increasing solar tracking time. In the case of control system in the first generation was used a commercial hardware and the control software was developed [9].

In the second generation control system was developed specific task [10] and patented [11], which allowed greater flexibility in developing the control system and the actuator drive. The control system maintenance and parameter setting for field configuration routines was implemented. The control flexibility of this solar tracking system allows exploring new applications in photovoltaic systems [12]. In addition to the functional benefits provided to the parabolic trough prototype, the developed control system cost is only 20% of the cost of the commercial system.

4. Conclusions

In this paper practical experiences on the parabolic trough technology development in Mexico have been presented. Even at small size, the parabolic trough developed with 100% of Mexican work-force and up to 90% of domestic equipment provides very attractive alternative, making it suitable for industrial process heat. The development is making great strides towards its objective of validating parabolic trough technology at the industrial scale. Knowledge gained during start up regarding the construction, operation and maintenance activities illustrate that the development is beginning to meet one of its primary goal identifying problems and solutions that will result in reduced risk for construction of further demonstration plants. This development has also identified the potential of the Mexican industry for facing this kind of new developments. Studies are also underway to investigate the deployment of this technology within the Mexican industry where there is a great need of clean energy. The developments along these three generations of prototypes have resulted in a viable product for use in the generation of heat for industrial processes.

Acknowledgements

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